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WADC TECHNICAL REPORT 54-86

AN EXPERIMENT ON THE CODING OF NUMERALS FOR TAPE PRESENTATION

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DECEMBER 1953

WRIGHT AIR DEVELOPMENT CENTER

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Antioch College

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United States Air Force
Wright-Patterson Air Force Base, Ohio

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FOREWORD

This report was prepared by Antioch College under USAF Contract No. AF 18(600)-50 covering work on the principles of instrument presentation. The contract was initiated under Research and Development Order No. 694-31, "Principles of Instrument Presentation," and was administered by the Psychology Branch of the Aero Medical Laboratory, Directorate of Research, Hq, Wright Air Development Center, with Dr. James M. Vanderplas acting as Project Engineer.

ABSTRACT

One way of transmitting information to aircraft crews would be to automatically punch or print numerical information on tape in the airplane in response to radio or radar signals. The tape may be scanned by a device to take control action and also be monitored by people. A compromise system of marking the tape has to be worked out which is efficient for both mechanical and human scanning.

Twenty-four subjects were tested to determine the speed and accuracy with which they could read Arabic numerals and five systems of coded numerals. The experiment provides preliminary information about the applicability of certain principles of coding in the selection of numeral representations for the punch or printed tape method of presenting information to airborne personnel. All subjects were fastest and most accurate with the Arabic numerals and all but three were slowest with the code based on the position of a single dot on a grid. The fastest and most accurately read numeral system, excepting the Arabic, was the symbolic Arabic code which resembles the Arabic, but the numerals are printed with six straight line elements. The three codes based on the number of dots or lines were intermediate in terms of reading speed.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

Jack Bollerud

Jack Bollerud
Colonel, USAF (MC)
Chief, Aero Medical Laboratory
Directorate of Research

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EXPERIMENT ON THE CODING OF NUMERALS FOR TAPE PRESENTATION

One way of transmitting information to aircraft is to signal an airborne printer which prints or punches the signal on tape. The tape may then be scanned by a device which may take control action depending on the information received. In addition it is essential for some kinds of information that the operator in the airplane be able to read the tape efficiently. In piloted aircraft, reading the information would be necessary for monitoring the automatic equipment, keeping logs, and predicting a course of events which could not be done by automatic computers.

The best numeral system for the human operator would probably be Arabic numerals because of lifelong familiarity, but it would require such an extremely complex scanner that its use in airborne equipment would be impractical. At the other extreme of mechanical simplicity, the printer could have a single element which made a number of identical marks on the tape equal to the number transmitted in the signal. Since only five or six dots can be immediately subitized and more than that have to be counted, this would be a slow and inaccurate system for the operator (1). The purpose of this research is to get preliminary data which would help in determining the kinds of coding systems which should most profitably be explored in designing a numeral system for tape presentation for both visual and mechanical scanning. Numeral coding systems which maintain mechanical simplicity and which are also easily read by people are the ones which should logically be considered for methods of tape presentation.

THE CODES

Five numeral coding systems and the Arabic code were used in this experiment (see Fig. 1). The Arabic code was used in order to establish a baseline of comparison for the other codes. Code B, the symbolic Arabic code, was chosen as a system which resembles the Arabic code but requires only six scanning elements (lines) rather than the large number which would be required by the Arabic code. There are two dot codes, C and D, which are based on the number of dots, but the dots are differently patterned to help in the identification of visual number. Code E depends on the position of a dot on a nine square grid for presentation of a numeral. Code F is based on the number of short vertical lines in a row. Codes C, D and E would probably be better without zeros, but for the experiment we needed to represent zeros in order to indicate whether the other numeral should be in the unit or the tens position, since only one two-digit number appeared on each stimulus card. The codes were chosen to represent a wide range of code types in order to eliminate poor ones from further consideration and, in a preliminary way, to suggest the kinds of systems which would be promising for further research.

THE EXPERIMENT

Twenty-four college students with an age range from 16 to 24 years were used in six groups of four subjects each. The experimental design of the order of presentation of the codes to the groups of subjects is shown in Table I. All subjects were tested on all codes, but the order of presentation of the different codes to the groups of subjects was counterbalanced so that every code occurred in each serial position once and preceded and followed every other code once and only once. This procedure controlled for facilitory or inhibitory effects among the codes since all the codes were presented in the same session.

TABLE I

Experimental Design

The numbers in the table represent the order of presentation of the codes to the different groups of subjects.

SUBJECT GROUPS	CODES A	B	C	D	E	F
I	1	2	3	6	4	5
II	2	3	4	1	5	6
III	3	4	5	2	6	1
IV	4	5	6	3	1	2
V	5	6	1	4	2	3
VI	6	1	2	5	3	4

The subjects were tested individually while sitting at a table with the experimenter. Before being tested on a code, the subjects were given a single card with the ten Arabic digits and the ten coded digits of the particular code printed on it, in order to familiarise themselves with the code in a two minute learning session. The experimenter reviewed the coded numerals with the subjects and made sure that they understood the code. The subjects were permitted to keep the instruction card while being tested on a code, but the cards were referred to only rarely. An experimental trial consisted of reading as rapidly and accurately as possible 100 randomly assorted two-digit coded numbers ranging from 00 to 99 inclusive from a deck of 100 three-by-five index cards. The 100 cards of a single code were in a deck in front of the subject; he took the cards one by one, read the number on the card and put the cards on another pile after reading them. A five minute rest was given the subject after testing with each code. A record of the reading time for the deck and for the number of errors was kept by the experimenter.

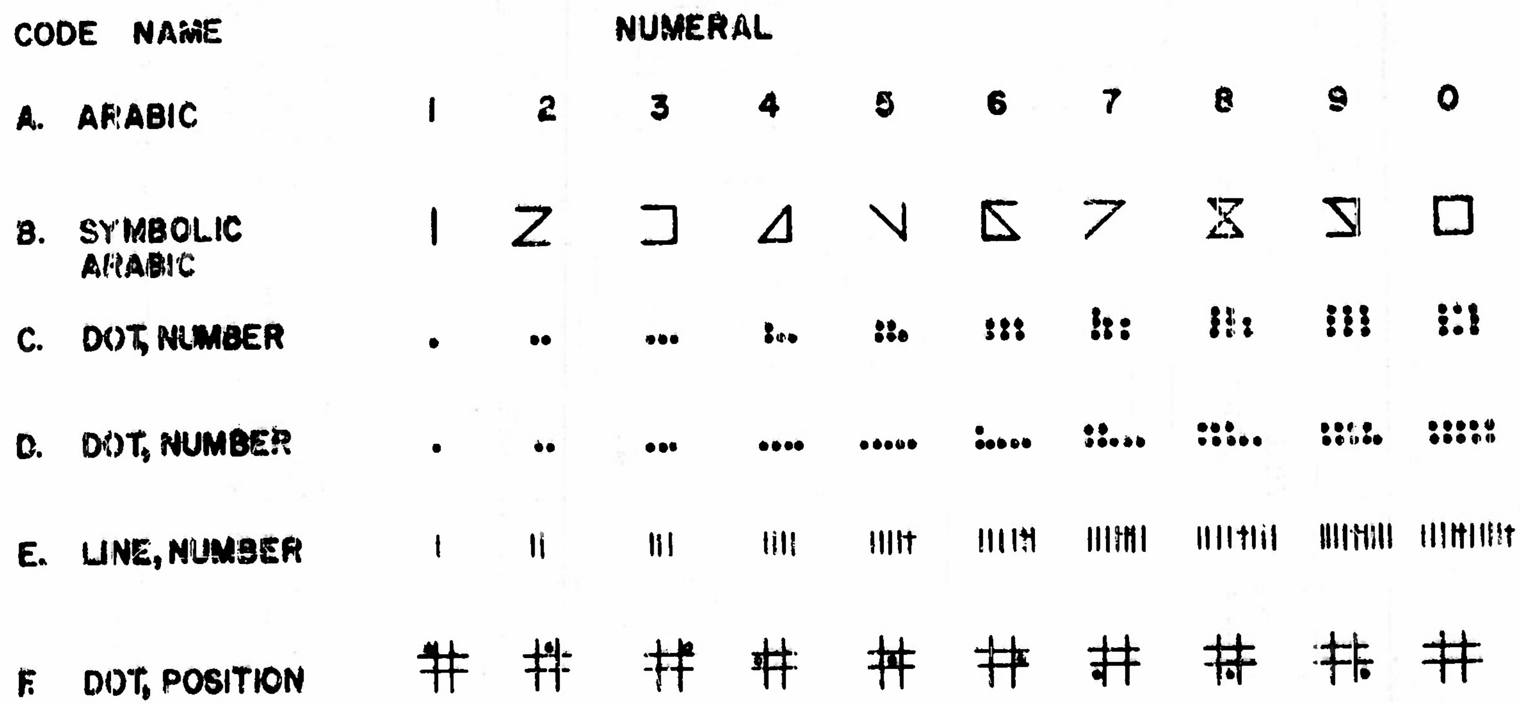

Fig. 1. Numeral codes used in the experiment.

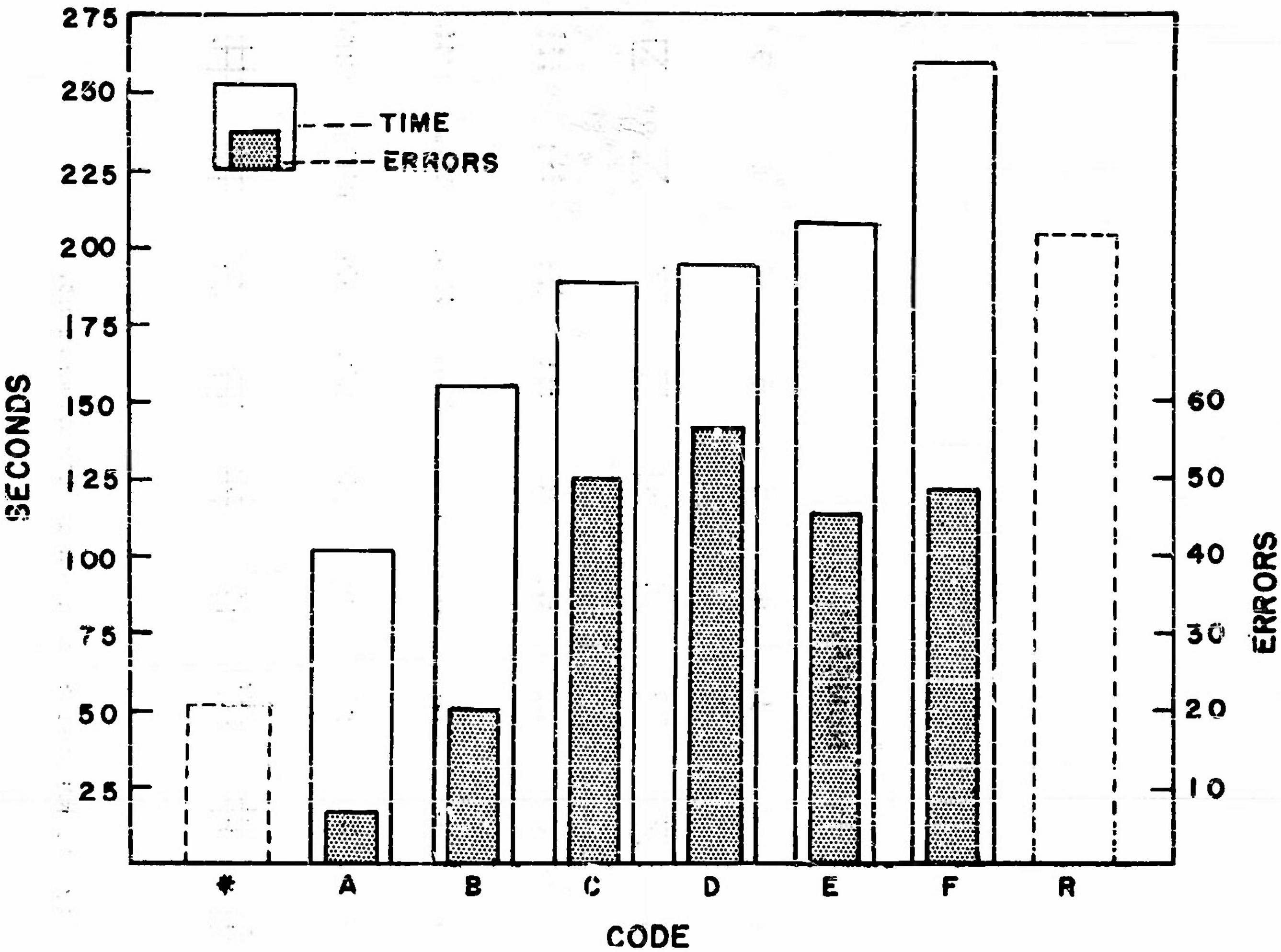

Fig. 2. Mean time to read 100 numbers and total number of errors made by 24 subjects. The empty columns represent time data and the filled columns represent error data. Perry's data on the time required to read Roman numerals converted to give results comparable to our own is presented by column R.

* The first column represents the handling time for 100 cards without reading numbers.

RESULTS

The average time it took the subjects to read a pack of 100 cards and the total number of errors in all the readings of all the subjects is presented in Figure 2. The time it took each subject to read each code is in Appendix I, and the particular errors which occurred are in Appendix II. Table II shows that the differences in mean reading times among the codes are significantly larger than would be expected by chance. The codes were ranked in order of the speed with which they could be read by each subject. The number of subjects who were fastest, second fastest, third, fourth, fifth or sixth fastest with each code is presented in Table III. It is not surprising that all the subjects were fastest with the Arabic code, but it is significant that nineteen of the twenty-four subjects were second fastest with the symbolic Arabic code, code B. Code F, the dot position code, resulted in the slowest performance for 21 of the subjects. The consistency of the rank orders of reading speed of the various codes from subject to subject is shown by Figure 3. The curve is the frequency distribution of rank order correlation coefficients obtained by correlating the rank order of the codes for each subject with every other subject. The Arabic code was omitted from the rank orders so as not to inflate the correlation coefficients which are based only on the five unconventional codes. If all the subjects had agreed on the rank order of codes all the rhos would have been 1.00. If there were no consistency in ranks, the rhos would have been distributed randomly around zero. The mean rho is .585 which indicates agreement among the subjects which is significantly greater than chance at the 1% level of confidence. Kendall's coefficient of concordance, "W," computed from the mean rho equals .60 which transforms to a "z" of .769 (2, pp.410-420). A "z" of only .647 is required for rejection, at the .01 probability level for 4 and 92 degrees of freedom, of the hypothesis that such agreement is due to chance.

A chi square test of the error frequencies, omitting the Arabic code, shows the codes to differ significantly in error production ($X^2 = 18.14$, $P = .01$ for four degrees of freedom ; X^2 of 18.46 is needed for a P of .001). Subjects are significantly more accurate with Code B than with the other four codes; since without code B the chi square is insignificantly larger than expected from chance differences ($X^2 = 1.56$).

DISCUSSION AND CONCLUSIONS

An experiment comparable to this one was done by Perry (3), who compared the reading speed of thirty subjects with Arabic and Roman numerals. The subjects read as rapidly as they could from typewritten lists of numerals for one minute and their scores were the number of numerals read aloud in that time. Mean reading times were presented for numerals ranging from 0 - 9, 10 - 49, and 50 - 99. In order to make these data comparable to ours, we weighted the means of the three number sets by the frequency of occurrence of numbers of a set in 100 randomly selected numbers. The weighted average

TABLE II

Values of "t" Ratios for the Pairs of Differences between the Reading Times of the Codes.

CODE B	C	D	E	F	CODE
30.74 *	____*	____*	____*	____*	A
	4.07*	3.96*	5.05*	8.64*	B
		1.06	2.24	6.49*	C
			1.34	6.50*	D
				6.27*	E

*Significant at the .001 level of confidence.

TABLE III

Rank Order of Codes with Respect to Reading Speed.

Entries represent the number of subjects for whom each code assumed a particular rank.

CODE	RANK 1	2	3	4	5	6
A	24	—	—	—	—	—
B	—	19	1	2	2	—
C	—	2	10	4 1/2	6 1/2	1
D	—	3	5	8 1/2	6 1/2	1
E	—	—	7	9	7	1
F	—	—	—	1	2	21

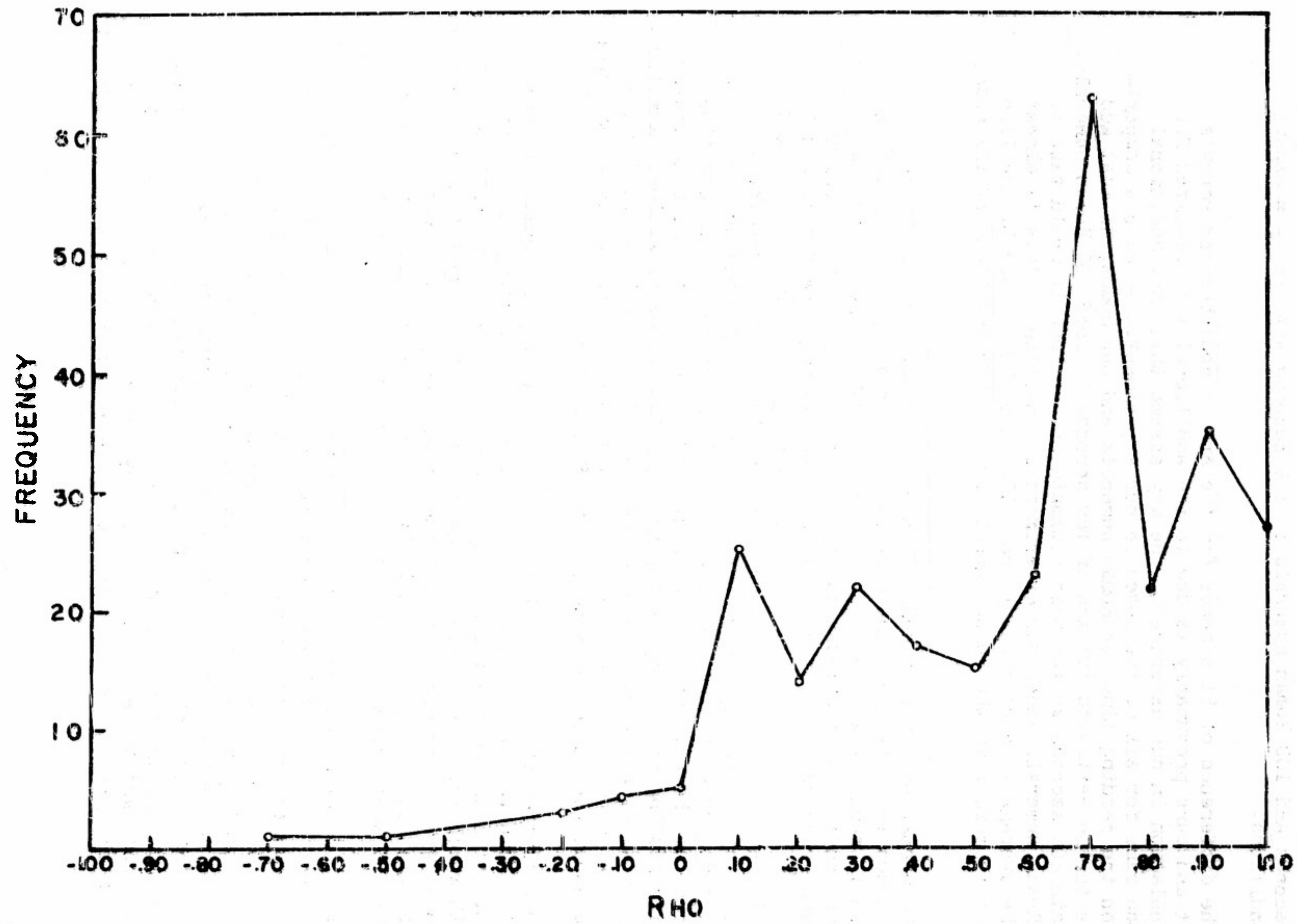

Fig. 3. Distribution of rank order correlation coefficients (rho) between every subject's reading speed of the codes and every other subject's reading speed of the codes, omitting Code A.

is 119.3 Arabic numerals per minute and 40.2 Roman numerals per minute. At those reading rates, 100 Arabic numerals could be read on the average in 50.4 seconds and 100 Roman numerals in 149 seconds with Perry's experimental conditions.

The difference of 51 seconds for the Arabic code between Perry's experiment and ours presumably is due to the additional time required for card manipulation in our experiment. We may assume that that additional time is the same for all of the codes in our experiment. To make a comparison between the reading time for Roman numerals and our codes, we must add 51 seconds to the estimated average of 149 seconds to read 100 Roman numerals, so we obtain 200 seconds as the best estimate of how long it would take to read 100 Roman numerals under our experimental conditions. This is almost exactly the average time required to read 100 numerals of code E, the line code, which is more like the Roman numeral system than any other of the codes we used.

The proper baseline of comparison of the reading times for the different codes is 50 seconds, the corrected mean reading time for code A, or the time it would have taken to read the 100 Arabic numerals were it not for the handling of the index cards. Subtracting 51 seconds from the obtained mean reading times, the corrected mean reading time for code B is 104 sec., code C is 142 sec., code D is 136 sec., code E is 212 sec., and code F is 151 sec. We can get the best idea of the relative reading speeds for the codes by expressing their corrected mean reading times as a ratio to the Arabic code corrected mean reading time. With the corrected mean time for each code as the numerator of the ratio and 50 seconds as the denominator, the relative reading speeds may be expressed by the following ratios: A = 1.00, B = 2.08, C = 2.72, D = 2.84, E = 3.02 and F = 4.24. Code B was read twice as slowly as A, codes C, D and E were read about three times as slowly and code F was read about four times as slowly as the Arabic code.

Some caution should be kept in mind in applying the results of this experiment. We have sampled only one point along the learning curve, and with additional practice and familiarity we may assume that the relative speeds with which the codes would be read could differ somewhat from our results. All the codes would probably be read faster with more practice, but it is very likely that code B would maintain its superiority over the other codes, and probably it would result in nearly as rapid reading as the Arabic code.

If engineering considerations make it unfeasible to build a lightweight scanner to interpret the conventional Arabic numerals, then a numeral system analogous to our code B should be considered. Its use by people is comparatively efficient since it resembles the Arabic code, and it may be automatically used by a scanner of six line elements. Code B should not necessarily be decided upon as the one to use in a practical situation, but only as a prototype of a whole class of numeral types that could be developed for the purpose. Future research should deal with the development of a symbolic Arabic code and the experimental display apparatus should resemble the display which is likely to be used in the airborne equipment. Another important

advantage of a code like B is that it could be used just as well to code the 26 letters of the alphabet for tape presentation of verbal material. Appendix III contains a suggested symbolic code system for letters based on eight line elements; this requires the splitting of the two center elements of the number scanner into halves or into four elements which can be activated separately.

Another possibility would be to have a dual system, so that a simple dot code could be used by the mechanical scanner, while the Arabic code could be superimposed on the tape for human scanning. The reading-time scores of code F compared with C, D and E suggest that a code based on the number of elements is superior to one based on the position of a single element. Code F was read significantly more slowly as tested by a "t" test than all the other codes. It seems to make little difference whether the elements are dots or lines but presumably the elements should be patterned to aid in the identification of visual number.

Only 1.88% of the 12,000 numerals were read incorrectly, so an extensive analysis of the particular error producing features of the codes is not possible. However, two outstanding sources of errors are apparent from an inspection of the error data, and certain features of the codes could be improved if they were considered for use. Half of the errors in code B involved the numeral "4" which was most often confused with "5". Confusion between the "0" and the "9" accounts for one third of the errors in code D. Taking 4/5 of the total errors for each code, as the expected frequencies, and the number of errors which occurred without counting stimulus numbers with a zero as the obtained frequencies, the chi square including code D is 19.12 (significant at the 1% level) and the chi square without code D is 2.08 (not significant). This indicates that code D would be considerably more accurate without a zero, but the use of a zero did not materially affect the accuracy of the other codes. However, codes like C, D and E would all be improved if in actual use a blank space in the proper column would designate zero rather than a symbolic representation. The tape with a long series of numbers would then present a graphical picture and the operators could get an idea of the magnitudes and trends presented without reading the actual numbers.

Since the accuracy of code D was materially affected by the omission of zero numbers, we wondered whether the speed of reading the code was also affected. Eight additional subjects were run on 100 cards of codes B and D from which zero numbers were omitted. The mean reading time of the two codes were similar to the means of the previous experimental groups and in favor of code B. Only one subject was faster on code D than B and the difference between the means of the two codes is statistically significant at the 5% point as tested by the "t" ratio of the mean difference divided by the standard error of the difference obtained by the difference method. We expected code B to result in faster reading so the "t" ratio of 1.89 is significant by a one tailed test. Further experimentation should be done with actual tapes prepared and read as they would be in a real situation in order to test the merits of a code like D or E in presenting a graphical picture.

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1. Kaufman, Edna L., Lord, M. W., Reese, T. and Volkmann, J., The Discrimination of Visual Number. *American Journal of Psychology*, 1949, *62*, pp. 498-525.

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3. Perry, D. K., Speed and Accuracy of Reading Arabic and Roman Numerals. *Journal of Applied Psychology*, 1952, *36*, pp. 346-347.

APPENDIX I

Table of Reading Time in Seconds for 100 Two Digit Numbers

CODE

	A	B	C	D	E	F
SUBJECT	ARABIC	SYMBOLIC ARABIC	NO. DOTS	NO. DOTS	NO. LINES	POS. DOT
1	96	133	179	187	184	207
2	102	138	182	159	155	218
3	68	112	137	127	114	160
4	107	167	204	176	185	221
5	86	115	135	175	197	226
6	130	168	235	206	238	297
7	121	160	175	161	193	224
8	91	133	231	198	230	246
9	79	137	186	237	225	263
10	107	128	187	198	213	208
11	88	144	200	187	160	195
12	88	124	181	208	153	180
13	119	152	259	271	351	429
14	140	183	168	199	218	339
15	123	216	231	190	208	377
16	100	136	189	228	228	352
17	88	140	164	143	218	244
18	90	122	141	162	153	258
19	116	185	222	277	254	338
20	104	168	191	251	232	271
21	81	184	166	209	173	350
22	98	139	183	178	183	246
23	99	196	157	144	154	211
24	105	235	175	164	232	251
MEAN	101	155	187	193	202	263

APPENDIX II

Table of Error Responses

CODE

A		B		C		D		E		F	
ARABIC		SYMBOLIC ARABIC		NO. DOTS		NO. DOTS		NO. LINES		POS. DOT	
S.[1]	R.[2]	S.	R.	S.	R.	S.	R.	S.	R.	S.	R.
11	01	43	40	74	54	30	80	92	91	84	74
03	30	35	34	11	22	70	90	86	36	47	46
50	55	25	75	06	96	30	80	12	03	46	56
60	61	24	74	88	77	69	79	11	02	07	06
80	82	42	47	29	20	07	97	83	73	68	38
73	37	23	73	31	32	04	94	98	99	93	83
		06	46	94	04	03	93	08	09	38	37
		95	65	97	07	01	91	58	48	62	61
		94	64	86	83	09	98	56	46	97	98
		91	61	87	97	00	99	33	83	53	52
		90	60	82	83	70	79	85	80	93	91
		76	75	31	41	58	59	29	19	68	38
		37	35	81	82	09	00	02	93	08	07
		94	90	50	40	73	72	08	98	58	28
		44	43	37	36	18	08	85	84	38	37
		74	54	35	36	76	71	12	13	80	70
		15	14	27	17	64	74	78	28	59	50
		24	20	28	27	52	42	32	31	26	16
		44	55	17	07	04	94	88	89	40	50
		46	56	62	32	76	71	86	96	68	38
				74	54	49	39	28	29	88	99
				76	86	94	93	59	69	71	17
				69	39	74	73	85	86	84	48
				60	30	20	29	95	05	82	28
				04	84	95	94	71	61	34	35
				52	42	97	92	69	60	07	70
				67	37	85	84	46	45	73	63
				85	75	07	57	78	28	08	18
				96	93	40	46	89	80	76	96
				49	39	97	07	18	17	73	71
				76	73	65	64	03	53	38	39
				53	73	78	79	08	58	17	18
				07	06	83	82	90	80	33	23
				64	63	58	53	05	15	81	71
				47	37	17	12	01	11	62	42
				40	30	68	63	92	32	50	60
				02	82	97	97	79	74	42	52

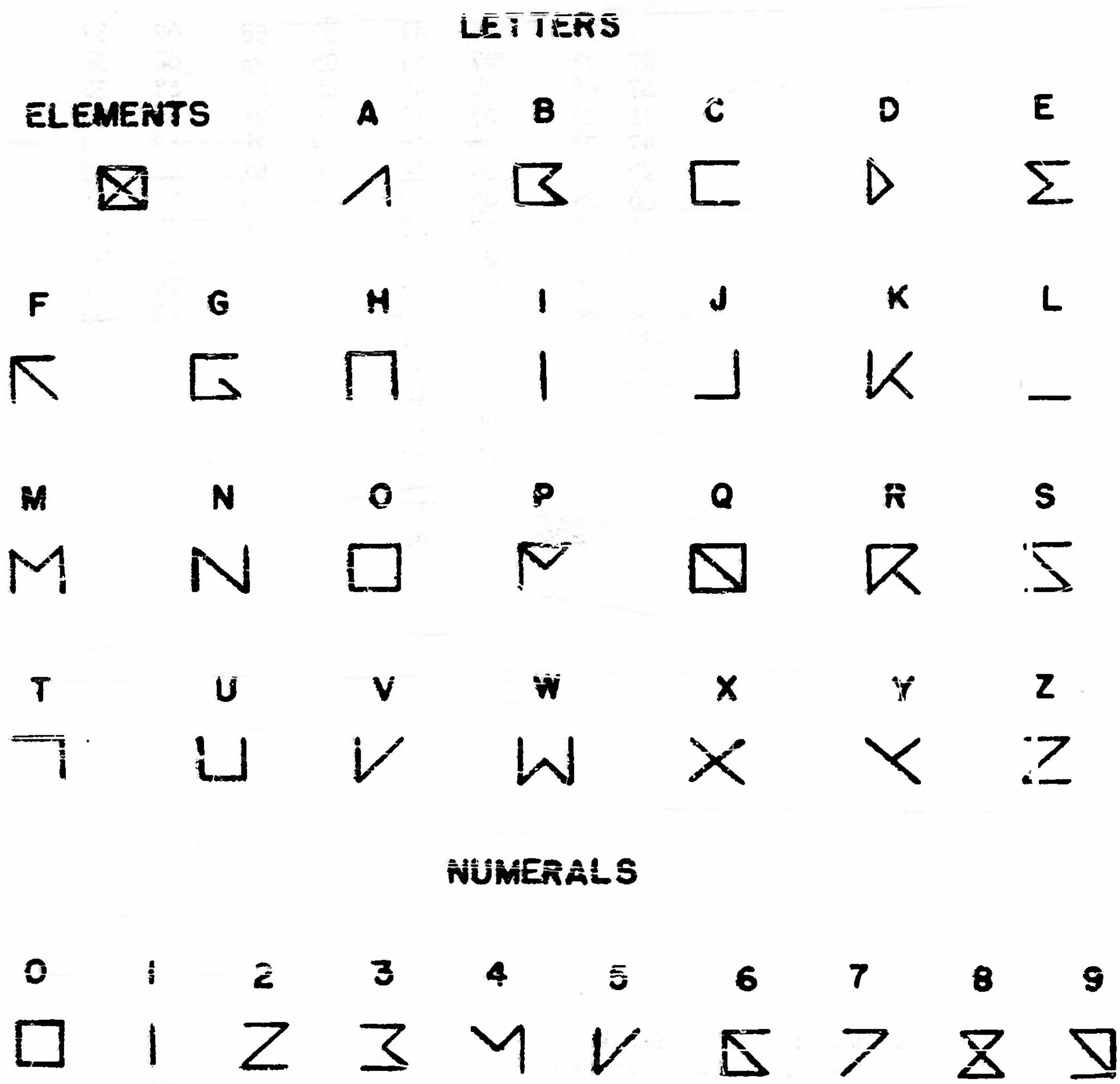
Table of Error Responses, cont.

A		B		C		D		E		F	
ARABIC		SYMBOLIC ARABIC		NO. DOTS		NO. DOTS		NO. LINES		POS. DOT	
S.	R.	S.	R.	S.	R.	S.	R.	S.	R.	S.	R.
				27	17	86	81	59	58	69	39
				87	97	87	57	05	95	62	32
				67	68	94	44	48	43	68	38
				21	23	07	17	76	71	60	30
				97	98	06	16	79	74	63	43
				79	69	04	14	86	81	56	23
				06	09	03	13	68	69	71	17
				13	14	43	47	29	24	84	48
				87	86	01	11			05	08
				37	36	09	19			76	67
				02	42	00	100			93	63
				38	36	10	01				
						57	52				
						02	12				
						05	15				
						08	18				
						20	29				
						07	97				
						53	43				
						57	47				

1. S is the number presented.
2. R is the incorrect response.

APPENDIX III

Suggested Symbolic Alphabet to Use for the Tape Presentation of Verbal Information



This alphabet requires an eight element printer. An eight element printer could result in improved presentations of numerals 3 and 4 as suggested in the above table, rather than as they were in the experiment.